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UNIVERSITY  
of  
NORTH CAROLINA  
Marine Sciences Program

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Dr. David Evans  
Office of Naval Research  
Code 1122 ML  
Physical Oceanography Program  
800 N. Quincy Street  
Arlington, VA 22217-5000

Dear David:

Enclosed is the Final Technical Report for the two-year long ONR contract entitled "Structure, Energetics and Dynamics of Gulf Stream Variability" which terminated on 31 December 1991. As you know, this contract provided support for our participation in SYNOP. Our continuing research on SYNOP is focussing on the scientific analysis of the extensive data sets collected during the field efforts of the past few years. This has been an interesting and exciting program in which to be a participant, and the support that ONR has provided for our work is greatly appreciated.

Please contact me if you have questions or would like further information.

Sincerely,

John M. Bane, Jr.  
Professor

copies to: Administrating Contract Officer (1)  
Director, Naval Research Laboratory (6)  
Defense Technical Information Center (12) (4)  
UNC Contracts and Grants (1)

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Statement A per telecon Dr. David Evens  
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Justification

## Structure, Energetics and Dynamics of Gulf Stream Variability

### FINAL TECHNICAL REPORT

Office of Naval Research Contract Number N00014-90-J-1596

*Submitted by:*

Prof. John M. Bane

Marine Sciences Program

University of North Carolina

Chapel Hill, North Carolina 27599-3300

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This is the Final Technical Report for the twenty-four-month-long Office of Naval Research Contract Number N00014-90-J-1596 to the University of North Carolina at Chapel Hill. Dr. John M. Bane, Jr., Professor in the Marine Sciences Program, was Principal Investigator for the contract period, which began 1 January 1990 and ended 31 December 1991. Total award for this period was \$190,000.00. The internal account number at the University of North Carolina was 5-35761. The work carried out with this funding was closely coordinated with a companion project at the University of Rhode Island, which had Dr. D. Randolph Watts as the Principal Investigator. Additional funding for this research was awarded to both UNC and URI by the National Science Foundation.

This contract supported research on the physical oceanography of the Gulf Stream as part of the SYNoptic Ocean Prediction (SYNOP) Program. The objective of the research was to increase our understanding of the structure, energetics and dynamics of the Gulf Stream in the western portion of the SYNOP study area, which is between 75°W and 67°W, where Gulf Stream meanders are of large amplitude and still growing, and where the activity of the adjacent ring and eddy field is vigorous. To address this objective, direct measurements were made with an array of current meter moorings and inverted echo sounders (IESs) with bottom pressure sensors, arranged to observe the oceanic time-varying velocity, temperature, and pressure fields on a three dimensional grid of sites. The array spanned essentially the full Eulerian mean width of the Gulf Stream current (Figures 1 and 2). The moorings extended from the deep water up through the main thermocline into the strong flow of the Gulf Stream jet. Three of the moorings held upward-looking Acoustic Doppler Current Profilers as part of W. Johns' (Univ. of Miami) experiment. This array was embedded

within a meander- and ring-mapping array of IESs that was part of an associated SYNOP task entitled "Gulf Stream Inlet-Conditions and Meander Tracking Experiment" (D. R. Watts, Univ. of Rhode Island, P. I.).

We completed the field-work phase of this component of SYNOP with the recovery of all instrumentation from the Inlet and Central Arrays in August-September 1990. The work at sea was performed aboard the *R/V Endeavor*, operated by the University of Rhode Island. It was a major logistical effort, coordinating technical groups at URI, the Woods Hole Oceanographic Institution and the University of Miami. All current meter data have now been processed and documented. Several segments of the data set have been shared with SYNOP modeling groups in order to begin the process of incorporating real-world data into models for initialization, updating and verification.

In a recently completed M. S. thesis, *Blanton* [1991] used data from the Gulf Stream Dynamics Experiment to evaluate two methods of estimating vertical velocities. Both methods are based on the nondiffusive heat equation, but the first depends on having data from only a single mooring and assumes the flow satisfies the thermal wind balance, while the second makes use of temperature and velocity data from several moorings and does not assume geostrophy. The two methods yield similar results, although the single-mooring method tends to produce more high-frequency vertical velocity variance and is more sensitive to the passage of isolated eddies. The mooring period was divided into a 6-month period when the Gulf Stream was over the array, bracketed by two 3-month periods when the Gulf Stream was flowing generally north of the array. During the Gulf Stream period, the magnitude of the vertical velocities increased severalfold over that of the earlier and later periods.

*Wang* [1991] has completed a model/data comparison study of the Gulf Stream downstream of Cape Hatteras. Using output from the NOARL 1/8th degree North Atlantic circulation model and data sets (including that from the Gulf Stream Dynamics Experiment), he has carefully compared aspects of the mean and fluctuating fields of the real and model Gulf Streams. For example, estimates of the surface eddy kinetic energy (EKE) fields based on GEOSAT data and EKE of the top layer of the model output show the field distributions have roughly the same shapes, with local maxima near 63°W and 50°W and a local minimum near 55°W. The western local maximum is about a factor of two higher in the model (when adjusted for the difference between the surface and upper-ocean average EKE), while the eastern maxima are the same within about 20%. Comparison of model-derived and measured current spectra has revealed a 5-6 day period fluctuation in each. This is the dominant period in the model cross-stream currents near 73°W, and it is associated with

the propagation of small-scale meanders through that area. This type of fluctuation also appears in the Gulf Stream path displacement time series derived from IES data, suggesting that it is related to meander propagation in the real Gulf Stream as well.

Our research group has continued to obtain high quality, *in situ* data sets within the strong flow of the Gulf Stream for the purpose of delineating its structure and dynamics. Vertical motions within the jet have been estimated using measured horizontal velocities and applied dynamical constraints. Detailed comparisons between model and real world Gulf Stream flows have been made and differences assessed.

Completed publications and presentations for which at least partial support was received from this contract are as follows:

Bane, J., T. Shay and S. Haines, 1990: Year 2 in the SYNOP Inlet and Central Arrays. *The SYNOPtician*, 1(6), pp. 1-2 and 10-14.

Shay, T., and J. Bane, 1990: Preliminary Results from Year 1 of the SYNOP Central Array Current Meter Moorings. *The SYNOPtician*, 1(1), pp. 1-3 and 13-17.

Shay, T. J., S. Haines, J. M. Bane and D. R. Watts, 1991: SYNOP Central Array Current Meter Data Report: Mooring Period May 1988-September 1990. *Univ. North Carolina Tech. Rept.*

Blanton, Sankey L., 1991: Vertical Velocities in the Deep Gulf Stream. M. S. thesis, University of North Carolina, 84 pp.

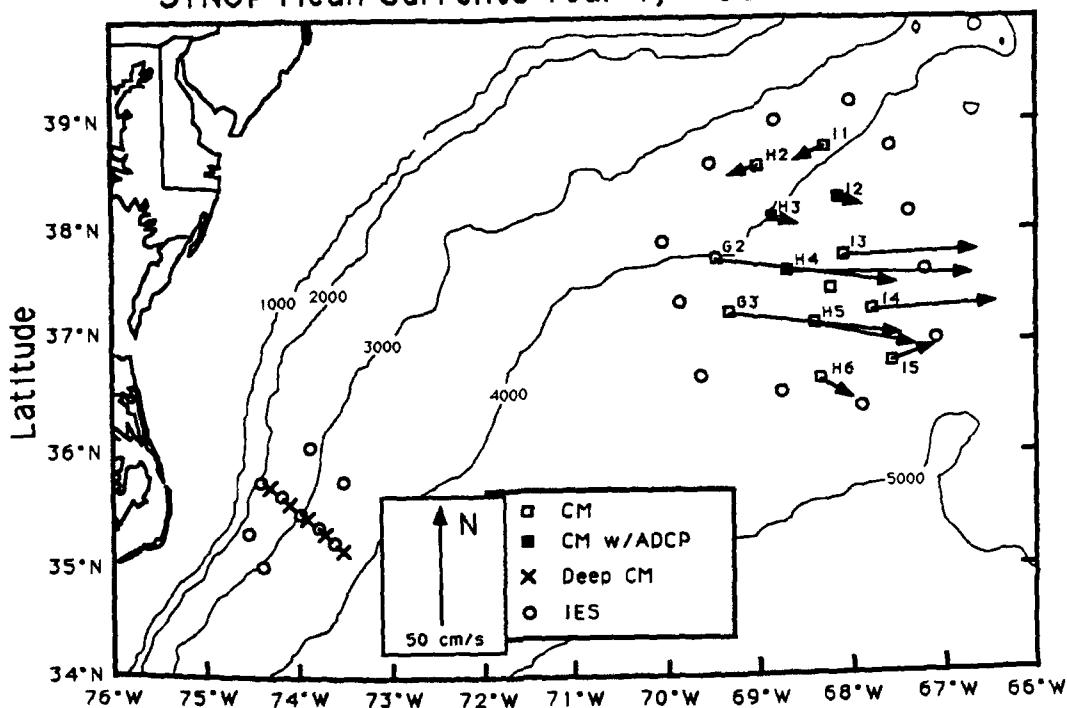
Wang, Wei, 1991: The Gulf Stream Downstream of Cape Hatteras: Model/Data Comparisons. Ph. D. dissertation, University of North Carolina, 116 pp.

Bane, J., 1990: SYNOP: Investigating the Dynamics and Predictability of the Gulf Stream. *Trans. Am. Geophys. Un.*, 71(2), p. 155 (abstract). Invited paper presented at the AGU/ASLO Ocean Sciences Meeting, New Orleans, Feb. 1990.

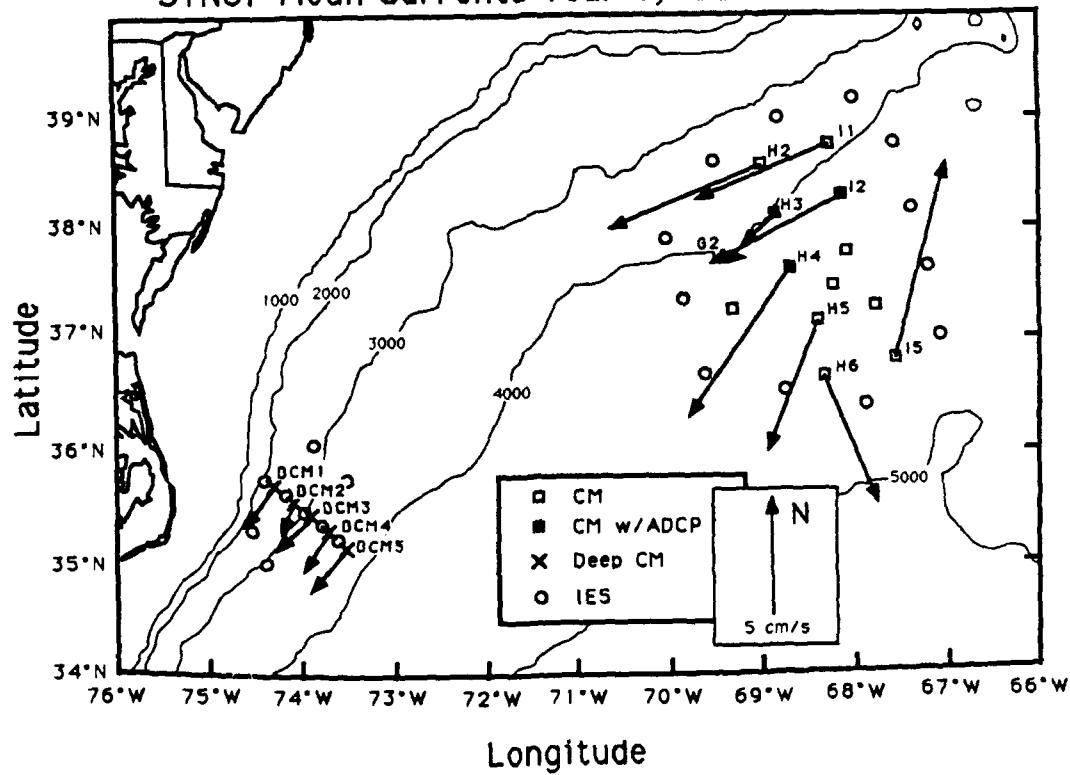
Bane, J., 1991: Detecting Isolated Coherent Eddies with a Moored Array. Presentation made at the SYNOP Workshop, Woods Hole Oceanographic Inst., September 1991.

- Bane, J., and D. R. Watts, 1990: Preliminary Results form the SYNOP Inlet and Central Arrays. Part I: Current Meter Measurements. *Trans. Am. Geophys. Un.*, 71(43), p. 1403 (abstract). Paper presented at the AGU Fall Meeting, San Francisco, Dec. 1990.
- Schultz, J., and J. Bane, 1990: Structure and Propagation of Deep Topographic Rossby Waves Northeast of Cape Hatteras during 1984. *Trans. Am. Geophys. Un.*, 71(2), p. 182 (abstract). Paper presented at the AGU/ASLO Ocean Sciences Meeting, New Orleans, Feb. 1990.
- Shay, T, 1991: Demonstration of SYNOP Central Array Graphical Display System. Presentation made at the SYNOP Workshop, Woods Hole Oceanographic Inst., September 1991.
- Shay, T. J., and W. E. Johns, 1991: Mean Characteristics of the Gulf Stream at 68°W During the SYNOP Central Array Experiment. *Trans. Am. Geophys. Un.*, 72(51), p. 57 (abstract). Paper presented at the AGU/ASLO Ocean Sciences Meeting, New Orleans, Feb. 1992.
- Wang, W., 1991: The Gulf Stream Northeast of Cape Hatteras: A Model-Data Comparison. Presentation made at the SYNOP Workshop, Woods Hole Oceanographic Inst., September 1991.
- Wang, W., J. M. Bane and J. D. Thompson, 1991: Gulf Stream Variability Downstream from Cape Hatteras: A Model-Data Intercomparison Study. *Trans. Am. Geophys. Un.*, 72, p. 161 (abstract). Paper presented at the AGU Spring Meeting, Baltimore, April 1991.
- Watts, D. R., and J. Bane, 1990: Preliminary Results form the SYNOP Inlet and Central Arrays. Part II: Inverted Echo Sounder Measurements. *Trans. Am. Geophys. Un.*, 71(43), p. 1403 (abstract). Paper presented at the AGU Fall Meeting, San Francisco, Dec. 1990.

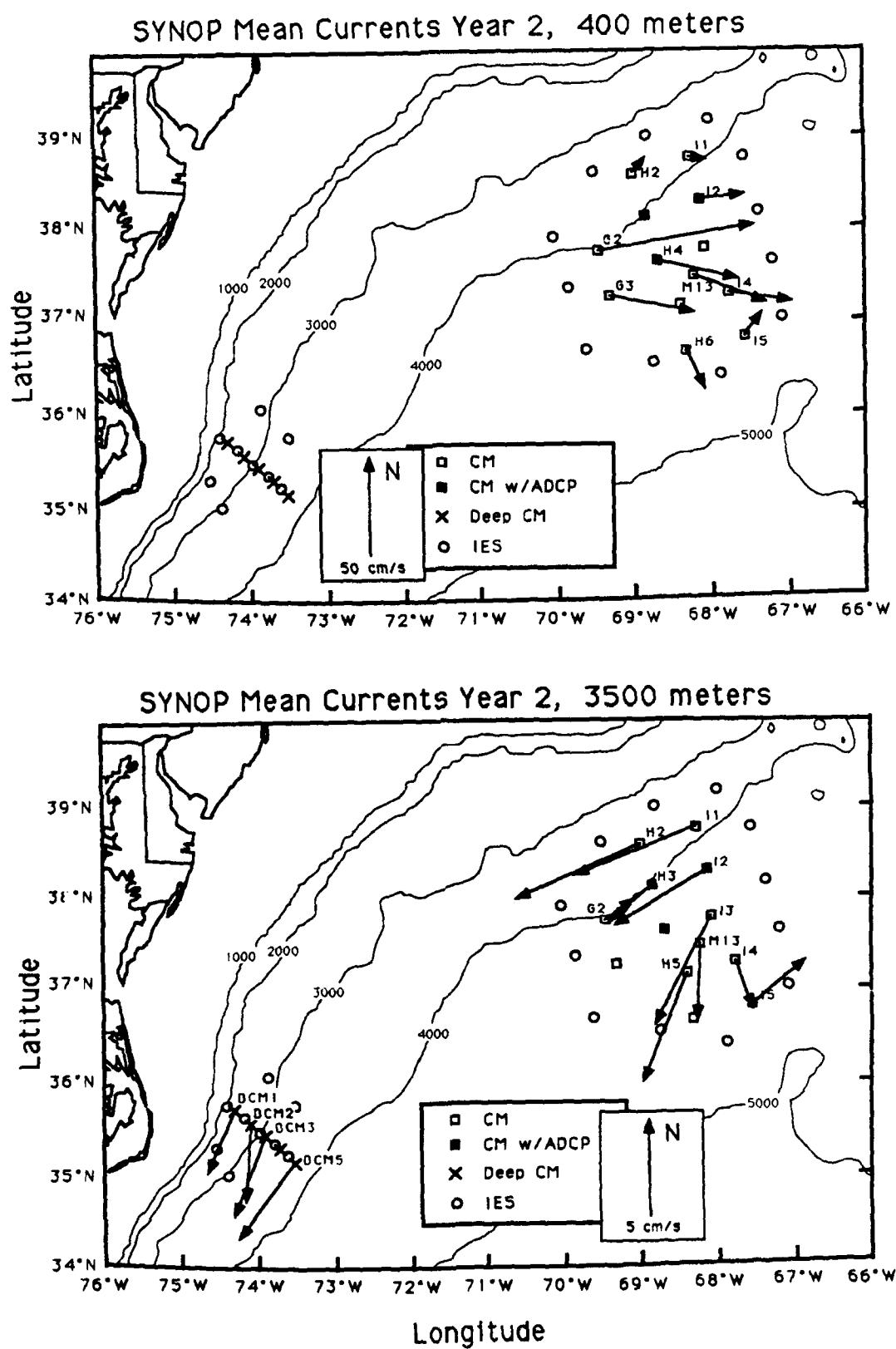
### SYNOP Mean Currents Year 1, 400 meters



### SYNOP Mean Currents Year 1, 3500 meters



**Figure 1.** Mean current vectors at two levels in the SYNOP Central Array (centered along 68°W) and at 100 m above the bottom in the SYNOP Inlet Array (centered along 74°W) for the first year of measurement (summer 1988 - summer 1989).



**Figure 2.** Mean current vectors at two levels in the SYNOP Central Array (centered along 68°W) and at 100 m above the bottom in the SYNOP Inlet Array (centered along 74°W) for the second year of measurement (summer 1989 - summer 1990).